Increased Launching Capabilities at AEDC's Range/Track G*

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Abstract

In 1993 AEDC's Hypervelocity Range/Track G went through a major upgrade to its model launching capability. A large, two-stage light gas gun with a 3.3-in. (84 mm)-bore launch tube was installed to provide a "soft launch" capability unmatched anywhere else in the world. "Soft launch" capability means subjecting the launch package to the minimum peak acceleration load for any given package weight and launch velocity. This capability allows the customer to launch the highest fidelity package possible at his conditions. The heart of this launching capability is a 14-in. (356 mm) pumping system that deliver even greater capability than the initial design goal.

This paper describes two other significant launching capabilities that have been realized because of the capability of the 14-in. (356 mm) pumping system. The requirements for the capabilities have stemmed from the lethality assessment of major BMDO programs such as THAAD, PAC-3, and NMD.

In 1995 a requirement to launch 1/2-scale THAAD projectiles at 4 km/sec generated an upgrade that resulted in an 8-in.-bore (203 mm) launch tube addition, 45 ft (13.7 m) of 8-in. (203 mm) track, and a significant increase in the hydrogen charge. This addition, along with a unique dynamic finite element analysis (FEA) modeling capability for projectiles, gave a tremendous increase in launching capability.

In 1996 a requirement to launch full-bore 40-percent scaled PAC-3 projectiles at 3 km/sec, generated an upgrade that resulted in a 4-in.-bore (102 mm) launch tube addition, 100 ft (30.5 m) of 4-in. (102 mm) bore track, and a capability to pitch the model.

This paper describes in details these upgrades to AEDC's Hypervelocity Range/Track G, and describes how these capabilities help meet the Impact Lethality Test and Evaluation requirements.

8-in. Launcher Development

Introduction

In FY94 BMDO approached AEDC about the capability to launch a half-scale model with a mass of 8 kg to a velocity of 4 km/sec. In response, AEDC proposed to convert its 14-in. (350 mm) pump tube driver for the 3.3-in. (84 mm) launcher to a driver for an 8-in. (203 mm) launch tube (See Fig. 1).

Fig. 1. 14-in. (350 mm) pump tube.

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This arrangement was unconventional because it would compress the driver gas through a 3.3-in. (84 mm)-diam orifice at the High Pressure Section and then expand it into an 8-in. (203 mm) launch tube (See Fig. 2). However, this installation arrangement could be expedited to meet the schedule requirements and it would be much more economical.

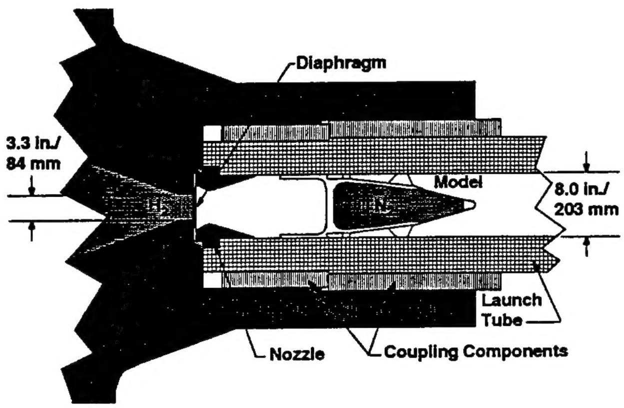


Fig. 2. High-pressure section orifice.

BMDO also wanted to control the angle of attack on the launched projectile before it impacted the target. To accommodate this, AEDC proposed to couple approximately 45 feet (13.72 m) of 8-in. (203 mm)-diam track to the muzzle of the launcher (Fig.3). The track would allow the venting of the muzzle gases as the projectile was guided through the muzzle blast zone and eliminate any induced angular disturbance from the muzzle gases. This technique has been used successfully at AEDC to

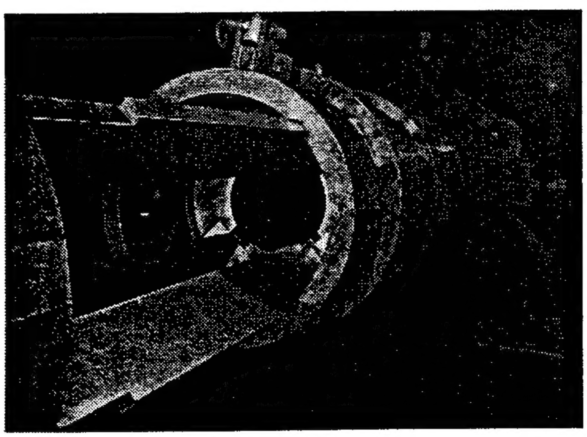


Fig. 3. 8-in. (203 mm) track/launcher muzzle.

control the model angle of attack when models are launched in free-flight mode.

In addition, BMDO wanted the model to replicate the real vehicle as close as possible, both in looks and mass distribution. The large 8-in. (203 mm) bore of the proposed launcher made it geometrically possible to launch a true half-scale model of the real THAAD flight vehicle. However, to achieve a length and mass distribution comparable to the real vehicle (high fidelity), the peak g-load of the launcher cycle had to be controlled within the 20-30 kg range.

High-Fidelity Model

To meet this goal, AEDC personnel modified the AEDC Launcher Code with the necessary mathematical changes for the new, unconventional geometry. After the code modifications were complete, numerous computer runs were made to optimize the launcher cycle for minimum g-load at the desired condition. This process eventually translated into a 133-ft (40.5 m)-long barrel. It was determined that this would reduce the g loads to 29 kg instead of 45 kg for a 100-ft (30.5 m) barrel length and provide the best chance of successfully launching an 8-in. (203 mm) high-fidelity model.

The 100-ft (30.5 m) barrel length was the original proposal because the 3.3-in. (84 mm) mounting system accommodated that length. In order to add to its lengths, the launch tube had to be extended into the Blast Tank because there was no room to relocate the launcher. This required the addition of a launch tube mounting system to the Blast Tank (Fig. 4).

Conversion Process

The conversion process was somewhat unique because of the 3.3-in. (84 mm) orifice in the high-pressure section but otherwise straightforward. There was additional risk in this approach over the conventional "no orifice" approach. To our knowl-

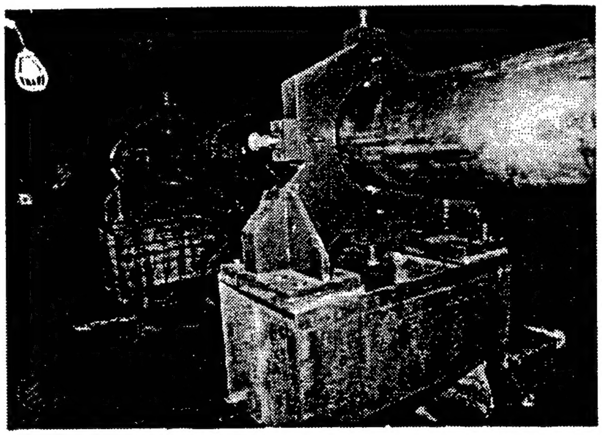


Fig. 4. Blast tank launch tube mounting system.

edge this configuration had never been tried before to this degree and it could not be modeled correctly on our one-dimensional gun code.

The 8-in. (203 mm)-bore launch tube was configured from 132 ft (40.2 m) of surplus pump tube (See Fig. 5). The tube contained four equal-length sections and required four coupling assemblies to mate it to the driver. Two complete coupling assemblies were available, which required only two to be fabricated. The outside diameter of the tube fit the adjustable range of the 3.3-in. (84-mm) steadyrest mounting system; therefore, no modifications were required for mounting. The opening in the blast tank had to be enlarged, however, to accept the slightly larger outside diameter of the tube.

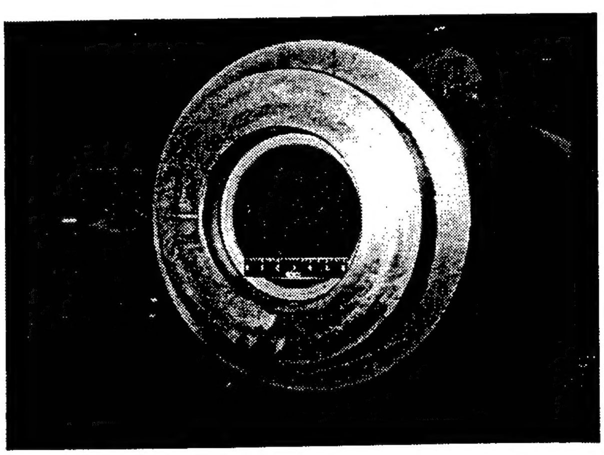


Fig. 5. 8-in. (203 mm) launch tube breech.

The Nozzle Adapter was designed with only geometrical considerations in mind. The Nozzle had to function as a 10-in. (254-mm) pilot on the outside diameter and as a bore transition from the 3.3-in. (84-mm) throat diameter at the High Pressure Section to the 8-in. (203 mm) bore diameter at the model loading point (see Fig. 2).

The Blast Tank mounting system for the launch tube was designed using surplus 3.3-in. (84-mm) steadyrests mounted on individual support stands inside the Blast Tank. Care was taken to locate the stands close to tank stiffening rings; in addition, large surface area mounting pads were attached to the tank wall to improve stiffness.

Licensing

The Ballistic Range Complex at AEDC is required to have a site license for conducting operations using explosives. The ranges also use hydrogen in combination with the explosives; therefore, AFMC Air Force Safety personnel must approve quantities of both.

The prior site license agreement for the G Range Complex set the limits at 200 lb (90.8 kg) of explosives and 7 lb (3.2 kg) of hydrogen. This quantity was deemed large enough to operate the 3.3-in. (84 mm) launcher over its anticipated envelope, but was only a third of the quantity needed to operate the 8-in. (203 mm)) launcher for the conditions required.

After a thorough examination of the 8-in. (203 mm) launcher cycle, it was determined that the license would require an upgrade to 400 lb (182 kg) of explosives and 21 lb (9.5 kg) of hydrogen.

Normally, these increases would have created difficulties in trying to adapt gun components like the powder chamber size and the hydrogen charge system to handle such large changes. However, both systems required only minor modifications to

cover the increases because of the additional capability built into the systems during the 3.3-in. Launcher installation in 1993.

To obtain the license, AEDC had to demonstrate to the "approving" officials that there were multiple layers of safety countermeasures in place to handle any emergency. These countermeasures seek to: (1) Prevent any hydrogen from escaping into the launch room through the use of launcher assembly procedures and leak checks; (2) Detect any escaping hydrogen well below the flammability limit and shut down the hydrogen charge system; (3) Ventilate the area profusely to prevent any possible buildup of escaping hydrogen inside the launch room; (4) Remove any possible ignition sources from the launch room by following the National Electric Code for hydrogen approved service; (5) Evacuate and secure the launch room to personnel before the hydrogen charging operation begins; and (6) Interlock all safety systems to ensure compliance.

Model Design

After the configuration was set and the loads were defined, model design began. This was the first opportunity to fully design a model using guidance from "FEMOD," a dynamic stress analysis computer code using finite element techniques developed and configured for AEDC's light-gas gun model analysis by QUEST Integrated, Inc. under an AEDC Small Busines Innovated Research (SBIR) contract.

The axisymmetric dynamic simulation is a four-step process: (1) The AEDC launcher code is run to predict the base pressure profile that the model would experience during launch from the light-gas gun (Fig. 6); (2) The model is designed using AutoCAD* and standard manual stress techniques tailored to the maximum g loads of the launcher cycle; (3) The model assembly is imported into

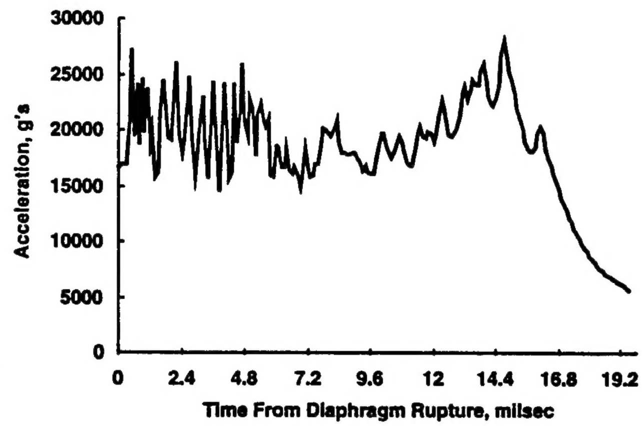


Fig. 6. 8-in. (203 mm) launcher acceleration profile (8 kg at 4 km/sec).

"FEAMOD" along with the full base pressure profile from the launcher code, and run; (4) The results are then used to adjust the model design and run again. The fourth phase continues until a satisfactory solution is achieved.

A computer run that simulates the full launch acceleration profile will generally require about 30 to 40 hours to run on a highly equipped RISC 6000 computer, depending on the mesh grid size and the integration step size used.

Since the model package in some instances is not symmetrical about its centerline, compromises were required in the simulated design. Although undesirable, the compromises made in the analysis setup to accommodate the capabilities of the analysis code did not significantly change the results.

The stress distribution of the final model designed is illustrated in Fig. 7. The graphic of this figure is produced by PATRAN,** an interface program that generates the input file for FEAMOD and manipulates the output produced by FEAMOD.

Figures 8 and 9 document the progression of the 8-in. (203 mm) model as it transitioned from a long design with no pitch inducement to a shorter design with internal pressure.

* AutoCAD is a registered trademark of Autodesk Inc.

** PATRAN is a registered trademark of MacNeal-Schwendler Corp.

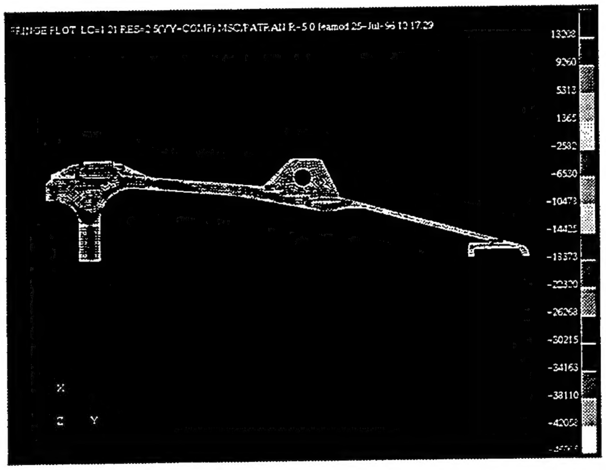


Fig. 7. FEAMOD analysis of final 8-in. (203 mm) model.

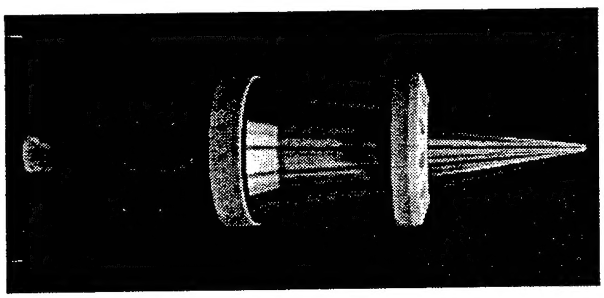


Fig. 8. 30-in. long, 8-in. model.

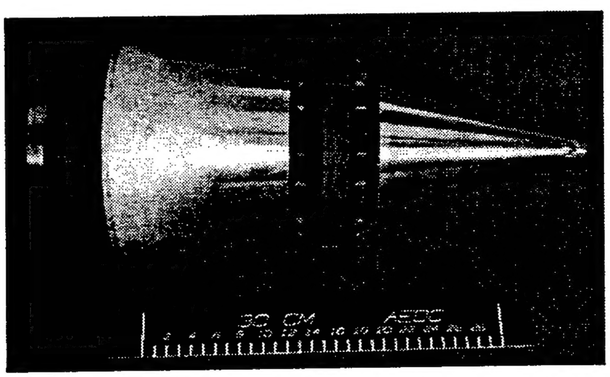


Fig. 9. 20-in. long, 8-in. model.

Work is currently underway to upgrade the software and hardware so that full 3D simulations can be obtained when needed.

Angle of Attack

The gas jet technique consists of pressurizing the internal model cavity with an inert gas before launch then allowing the gas to escape through an orifice at right angles to the flight path during launch. The gas is allowed to escape when a shuttle valve is opened as the model undergoes acceleration loads. Of course, it is crucial that the model come out of the launcher with the jet orifice aligned with the plane of desired pitch.

To prevent the rotation of the model in the bore, a polished bore surface finish was required. This was achieved by honing the launch tube bore using several different honing stone grades until the desired surface was obtained.

8-in. Development to Date

Four shots have been conducted to date using the 100-ft (30.5 m) version of the 8-in. (203 mm) Launcher. All objectives were met and costs were within expected limits. Nineteen shots have been conducted utilizing the 133-ft (40.5 m) version of the 8-in. (203 mm) Launcher. All but eight shots of the latter nineteen were provided with angle-of-attack capability.

The Launcher Performance Curve for all twenty-three 8-in. Launcher shots is plotted in Fig. 10.

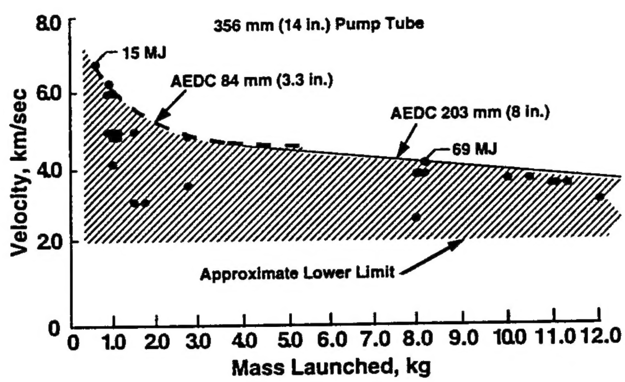


Fig. 10. 3.3- (84 mm) and 8-in. (203 mm) launcher capability.

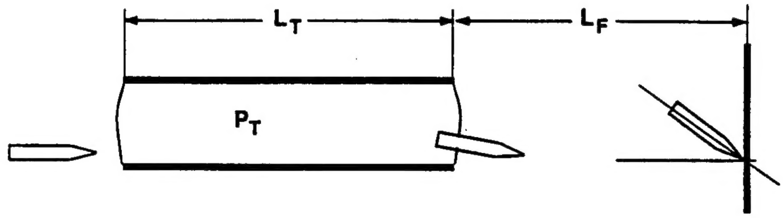
4-in. Launcher Development

Introduction

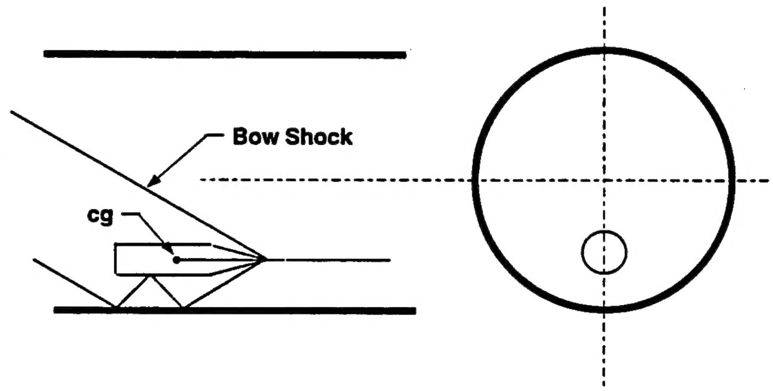
In 1996 the PAC-3 Live-Fire program had requirements to launch 5-kg scaled models with a

specified angle of attack at velocities up to 3 km/sec. In addition to these requirements, the model had to provide kill results at a comparable velocity similar to those demonstrated previously at full scale on the Holloman Sled. This meant the model had to have a weight distribution as similar as possible to the flight vehicle.

Most ballistic range testing people are aware that it is a difficult structural task to produce a weight distribution for a gun-launched model that is similar to a flight vehicle. The difficulty lies in the order of magnitude difference in the g-loads experienced by a gun-launched model and that experienced by a rocket-launched vehicle.



a. Pitch-inducing apparatus



b. Shock reflection

Fig. 11. Reflecting Plane Pitching Technique.

During the course of the review, it was also learned that both a 50-percent scale version and a 40-percent scale version were under consideration. AEDC's 8-in.-bore system is capable of launching the 0.5-scale version of the model, but a required sabot would complicate the accuracy of the angle-of-attack inducement capability.

A decision was finally made to go with a 0.4-scale model so that a full-bore model could be utilized. This decision was also driven by some preliminary code validation work that was already in progress.

AEDC initially planned to use a technique called the "Reflecting Plane" to provide the angle-of-attack requirement. In this technique, a model is flown near a surface so its bow shock reflects off the surface of the plane and impinges behind the center of gravity of the model, thus giving it a pitching moment (Fig. 11).

A small "Reflecting Plane" technology effort, including CFD analysis and development shots, had been done at AEDC previously, and the results were encouraging.[1] This technique is attractive because it is independent of model roll orientation and does not require a pressurized cavity within the model, allowing for higher-fidelity model construction. However, the technique is sensitive to the initial angle of the model entry onto the reflecting plane. AEDC's approach was to use a portion of the Range G Track to control the initial conditions and overcome the sensitivity to initial angle. Unfortunately, the time available to solve the sensitivity issue was not provided, and the "Gas Jet Technique" was employed in the interest of time.

Design/Installation Process

The design process on the 4-in.-bore launch tube modification required adapting the 14-in.-bore pumping system on the 3.3-in.-bore launch tube in much the same way as the 8-in. modification. There was one exception, however. Since the bores were so similar in diameter, 3.3 in. and 4 in., there was no need for an adapting nozzle insert.

The 4-in. bore was simply mated to the 3.3-in. bore with no transition. The only other modifications required were to adapt the launch tube mounting system to the smaller tube diameter and adapt the launch tube sealing flange at the Blast Tank entrance. In addition, 100 feet of 4-in. track and a 4-in. recoil unit were also fabricated. An arrangement of this modification without the track addition is shown in Fig. 12.

This modification was a low-cost addition to the Ballistic Range capability at AEDC. It was all fabricated from items in storage or stock material. The 106 feet of launch tube used for the modification was salvaged from a previous launcher at the Navy Ordinance Lab (NOL) that had been in storage at AEDC since 1978.

The 8-in. modification which preceded the 4-in. modification had already provided large increases in the quantities of hydrogen and powder available for use; therefore, no other increases in the charging systems were required.

The results of this modification to the launching performance curve for the 14-in. pumping system are shown in Fig.13.

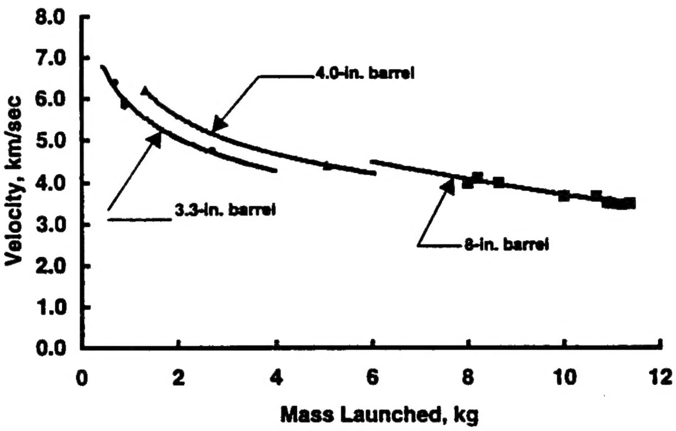


Fig.13. 3.3, 8, and 4-in. launcher capability.

This new capability provides another valuable tool for the assessment of lethality using ground testing techniques. Its larger size has already provided some badly needed flexibility that is required to achieve the demanding task of launching fragile, high-fidelity models at hypervelocity. In a recent test for the Navy, the 4-in. bore tube allowed a significantly more fragile model to be launched than would have been possible without it. The 4–in. bore provided enough area to maintain the 25-percent scale of the model and yet transfer all the model launch loads through the sabot and around a weak plastic component near the base of the model (Fig. 14).

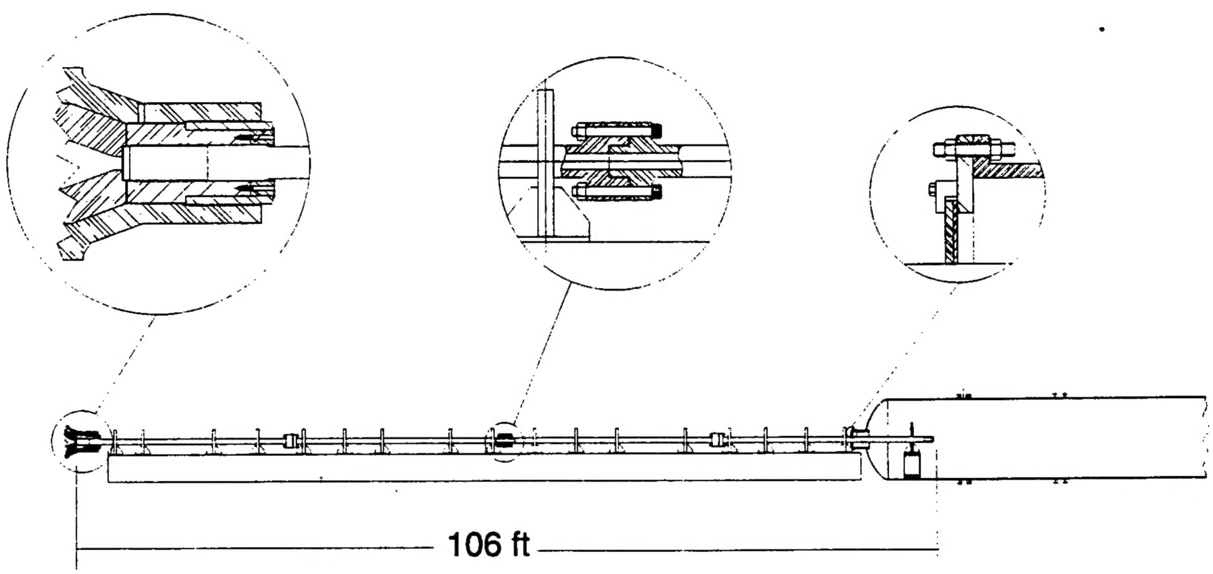


Figure 12. 4-in launcher installation.

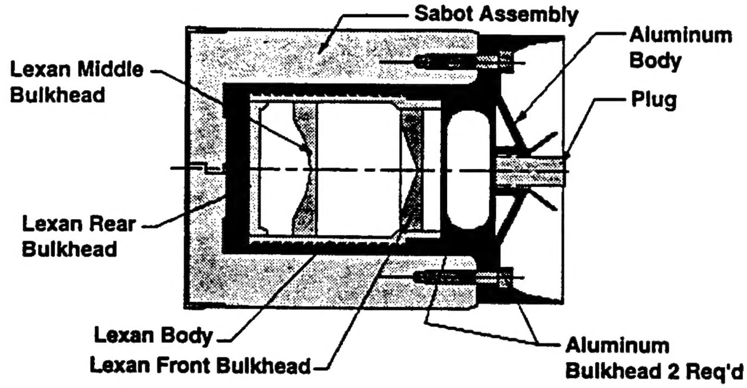


Fig. 14. 4-in. model with load carrying sabot.

This kind of innovation is a must if scaled Ballistic Range ground testing simulation is going to achieve near-flight test results at a much lower cost.

Summary/Conclusion

An 8-in. (203 mm) Launcher and a 4-in. (102 mm) Launcher with some supporting track has been developed at AEDC to meet the demanding requirements of current BMDO test programs.

The 8-in. Launcher has demonstrated the capability of reliably launching 17.6-lb (8 kg) high-fidelity models to a velocity of 4 km/sec (13,124 fps). Higher velocities are possible if acceleration loads are not a factor.

The 4-in. Launcher has demonstrated the capability to launch 2.8 lb (1,300 gm) models to velocities of 6 km/sec.

In addition, the capability to provide a predictable angle of attack for 8-in. (203 mm)-diam models and 4-in. (102 mm)-diam models has also been developed. The current angle-of-attack capability utilizes a gas jet process to achieve the required angle.

AEDC has also made significant improvements in its ability to launch fragile models with the aid of a unique dynamic axisymmetric FEA code. Work is currently underway to improve the modeling capability to include full 3-D simulations.

References

1. Young, Raymond P., "Lethality Assessment Test Capabilities of the Arnold Engineering Development Center," AIAA 95-0708 alt, 4th AIAA/ BMDO Technology Conference, July 18-21, 1995, Natick, MA.